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## Impact assessment of its applications for Vulnerable Road Users

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### Abstract

The EU-sponsored VRUITS project has prioritized ITS applications which have a potential to improve the safety, mobility and comfort of vulnerable road users (VRUs) and performed a quantitative safety, mobility and comfort assessment for the 10 most promising systems. The assessment methodology addresses not only the direct effects of the systems, but also unintended effects and effects through changes in mobility patterns. The 10 selected ITS were: VRU beacon system, Powered Two Wheelers oncoming Vehicle information, Bicycle-to-vehicle communication, Cooperative Intersection safety, Green wave for cyclists, Pedestrian & Cyclist detection with Emergency Braking, Blind spot detection, Intelligent pedestrian traffic signal, Crossing adaptive lighting and Information on bike rack vacancy. The paper presents the quantitative estimates for the impact on safety, mobility and comfort. The outputs of the impact assessment are translated into socioeconomic indicators via a social cost-benefit analysis.

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## 1. Introduction

ITS applications have assisted in reducing the number of accidents in Europe, but the development has mainly been vehicle-centric. The decrease in casualties of Vulnerable Road Users (VRUs), such as pedestrians, cyclists and Powered Two-Wheelers (PTWs), has been much less prominent. The VRUITS project, which is sponsored by the European Commission, has as main objective to provide recommendations for policy and industry on ITS applications to improve safety and mobility of VRUs. This paper presents the results of the impact assessment, providing quantitative estimates of the impacts on safety, mobility and comfort of selected ITS. The approach is based on the method introduced by Kulmala (2010), which was developed for the assessment of safety impacts of ITS for cars. The assessment method has been enhanced and adjusted to take into consideration the vulnerable road users and to cover mobility and comfort aspects of the systems. The comprehensive assessment method used has been described by Mans et al. (2014) and van Noort et al (2014).

This paper presents i) the results of quantitative safety, mobility and comfort impact assessment which was conducted to the 10 systems selected for quantitative impact assessment, and ii) the results of cost-benefit analysis (CBA) which was conducted to translate the safety, mobility and comfort impacts into socioeconomic indicators. The CBA method considered benefits in the field of safety, mobility (travel time and travel costs), comfort and environment.

The VRUITS project also included pilots of selected systems, such as cooperative intersection safety for cyclists in Helmond (the Netherlands) and intelligent pedestrian traffic signals in Valladolid and Alcalá de Henares (Spain). The results of our impacts assessment will be updated with the results of the pilots at the later stages of VRUITS project. The results of the impact assessment will be exploited to draw recommendations regarding the systems, which will allow the improvement of safety, mobility and comfort of VRUs.

## 2. Safety, Mobility and Comfort Assessment methodology

The adopted safety impact assessment method followed the steps reported by Kulmala (2010). In order to ascertain that all possible impacts (both positive and negative impacts on road safety; direct, indirect and unintended effects of systems) will be covered, and no effects are counted twice, the analysis utilises a set of nine mechanisms via which ITS can affect road user behaviour and thereby road safety. These nine mechanisms cover the three aspects of road safety in a systematic manner and are based on a ten-point list compiled by Draskóczy et al. (1998). These nine mechanisms were updated to be more focused on changes in behaviour of vulnerable road users and the situations they face in traffic (van Noort et al. 2014):

- Mechanism 1: Direct modification of the task of road users by giving information, advice, and assistance or taking over part of the task
- Mechanism 2: Direct influence by roadside systems mainly by giving information and advice
- Mechanism 3: Indirect modification of user behaviour in many, largely unknown ways
- Mechanism 4: Indirect modification of non-user behaviour
- Mechanism 5: Modification of interaction between users and nonusers
- Mechanism 6: Modification of road user exposure by for example information, recommendation, restrictions, debiting or increased comfort in car driving, PTW riding, cycling or walking
- Mechanism 7: Modification of modal choice by for example demand restraints, supply control by modal interchange and other public transport management measures, and travel information systems
- Mechanism 8: Modification of route choice by route diversions, route guidance systems, dynamic route information systems, and hazard warning systems monitoring incidents
- Mechanism 9: Modification of accident consequences by intelligent injury severity reducing systems at crashes, by quick and accurate crash reporting and call for rescue, and by reduced rescue time.

The adopted safety, mobility and comfort impact assessment method followed the following steps:

**Step 1. System descriptions (safety, mobility and comfort):** The process started by writing of comprehensive system descriptions so that everyone had a clear and convergent understanding on the systems under assessment, their functioning, technical limitations and anticipated user reactions and expected effects on safety, mobility and comfort. The descriptions were made for 23 systems selected from a large catalogue of systems, as having the potential to improve safety, mobility and comfort of VRUs. Scholliers et al. (2014) provides more information on the selection of the systems.

**Step 2. Description of effects (safety, mobility and comfort):** During this step the description of expected changes in driver and VRU behavior and documentation of the expected effects based on existing literature and other evidence available were done for each relevant mechanism.

**Step 3. Selection of systems for quantitative impact assessment (safety, mobility and comfort):** A set of 10 systems was selected for further assessment by using multi-criteria assessment and portfolio check. The 10 systems were: VRU beacon system (VBS), Powered Two Wheelers oncoming Vehicle information (PTW2V), Bicycle-to-vehicle communication (B2V), Cooperative Intersection safety (INS), Green wave for cyclists (GWC), Pedestrian & cyclist detection with Emergency Braking (PCDS+EBR), Blind spot detection (BSD), Intelligent pedestrian traffic signal (IPT), Crossing adaptive lighting (CAL) and Information on bicycle rack vacancy (IVB).

**Step 4. Estimation of effects by mechanism (safety, mobility and comfort):** In this step the earlier described effects of each safety, mobility or comfort mechanisms were presented in terms of % increase/decrease of relevant accidents, mobility or comfort. The reference case for the estimates was the situation without any ITS, and in most cases a linear development of effects was assumed. The support of external experts (1–13 per system) was used to check whether the assumptions made in the earlier phases of the assessment were correct and as background information when drawing the numerical estimates. The safety assessments were made step wise typically starting with the definition of target accidents and proceeding by providing estimate of effectiveness (low, medium, high). The first estimates of the effects were drawn by a small group of experts, who studied the relevant literature and system functioning in detail. These numerical estimates were reviewed among all safety experts involved in the impact assessment process to crosscheck and validate the estimates. The mobility and comfort assessments were also made step wise starting with the mobility or comfort baseline (i.e. the situation without the system) by providing estimate of effectiveness. The first estimates of the mobility and comfort effects were drawn by small group of experts, who studied the relevant literature and system functioning in detail. The mobility and comfort assessments consisted of several rounds of reviewing of the assumptions to reach a consensus on the numerical estimates of the comfort and mobility effects respectively. The estimates were iteratively crosschecked and thereby validated by the other experts. The assessment of mobility and comfort was conducted for all involved road user groups (pedestrians, bicyclists, moped- and motorcycle riders, car drivers and trucks drivers) of different ages (7–12, 13–17, 18–64 and older than 64 years) for 10 systems, and expressed as low, medium and high range. All road user groups were not of interest though for all systems.

This crosscheck and validation of estimates of safety, mobility or comfort was found especially important for assumptions for which there existed no proper literature. Lack of solid results from literature is a significant issue because many of the selected ITS are still in development, and hence little is known from experience. Furthermore, findings may depend significantly on the cultural and legal context, and on other circumstances (like level of urbanization, climate, etc.). Each of these aspects may differ widely between different EU countries and regions and hence it is a challenge to generalize findings across the EU. That being said, often literature can be found on direct effects (mechanisms 1 and 2), albeit often only for specific countries or situations. The indirect mechanisms (3–5) were found to be much harder to assess, and here we had to a much larger extent to rely upon expert judgement and knowledge on general behavioral mechanisms. Mechanism 9 was not relevant for any of the ITS under consideration.

**Step 5. Effects on exposure (safety, mobility and comfort).** The results of mobility and comfort assessment (Johansson & Bell, 2015) were directly used for the estimates regarding mechanisms 6–8. The effects of the modal change were only included for vulnerable road users. The effects of the modal change of cars, trucks and public transport were estimated to be insignificant. The estimated effects on VRU exposure were transferred to safety effects of exposure (same values for fatalities and injuries) based on the values found from earlier studies (Jonsson, 2005; Jacobsen, 2003; Marizwan et al., 2014 and previous impact assessment studies).

**Step 6. Estimation of penetration rates (safety, mobility and comfort):** For the estimation of the penetration rates for the systems, two questionnaires were developed for stakeholders involved. It is however very challenging for key stakeholders to make predictions on the implementation of innovative ITS technologies. The first questionnaire, which targeted to get input for both 2020 and 2030 and different VRU and vehicle classes, only received a low number of answers. Based on the inputs received, and on feedback retrieved during the VRUITS

Second Interest Group with the stakeholders, an estimate for the implementation rate in 2030 was made. A second questionnaire was then sent out to the stakeholders, and 34 replies from 14 countries were received. Based on these replies, low, medium and high ranges for the penetration were estimated. (García Meléndez et al., 2014).

Table 1. Estimated penetration rates for the selected ITS in 2030.

System	Parameter	Low	Medium	High	
IPT	Intelligent Pedestrian Traffic Signal	% of signalised intersections in urban areas	5%	25%	32%
CAL	Crossing Adaptive Lighting	% of pedestrian crossings in urban areas	6%	10%	18%
INS	Intersection Safety	% of signalised intersections in urban areas	2%	4%	5%
		% of vehicles (with C-ITS equipment)	15%	30%	40%
VBS	VRU Beacon System	% of pedestrians equipped	1%	4%	5%
		% of bicycles equipped	2%	12%	15%
		% of PTWs equipped	5%	32%	40%
PTW2V	PTW oncoming vehicle information system	% of PTWs equipped	5%	28%	36%
IVB	Information on Vacancy on Bicycle racks	% of bicycles equipped	5%	10%	25%
B2V	Bicycle to car communication	% of bicycles equipped	5%	8%	10%
GWC	Green Wave for Cyclists	% of signalised intersections in urban areas	0,5%	1%	2%
PCDS+EBR	Pedestrian & Cyclist Detection System+ Emergency Braking	% of vehicles equipped	24%	36%	49%
BSD	Blind Spot Detection	% of vehicles equipped	35%	44%	60%

**Step 7a: Estimation of accidents trends (safety):** A regression analysis of current accident numbers from 2002 to 2012 was conducted to forecast the accident numbers in 2020 and 2030 with the assumption that no system intervention had occurred between these dates (Hancox et al., 2015). These safety trends were separated by country cluster (based on previous safety track record within the EU), vulnerable road user type (pedestrians, cyclists, moped riders and motorcyclists) and accident severity ('fatal' or 'injured'). The analysis included the establishment of the ratio of accidents for 2020 and 2030 for every accident which occurred in 2012.

**Step 7b: Estimation of mobility and comfort trends:** The model used to describe future mobility trends was based on Chatterjee and Gordon (2006) which provides the basis for the assessment of four proposed scenarios with integrated technological and infrastructural innovations for the year 2030. The model describes four trends: World markets (WM), Provincial enterprise (PE), Global sustainability (GS); and Local stewardship (LS). The figures were used to calculate index's describing the mobility changes in different transport modes for the years 2012, 2020 and 2030 based on average values for the four trends. The safety trend described in accident numbers in 2020 and 2030 were used to calculate an index of comfort trend; improved safety leading to less accident led to improved comfort to the same extent.

**Step 8. Calculation of effects (safety, mobility and comfort):** The effect estimates per mechanism (from steps 3 and 5) were combined into an overall low and high estimate for each system, and subsequently applied to the EU-28 road accident data, so that the distribution of the main classifying variable (collision type) weighted the estimate i.e. it was assumed that the ITS under assessment was more effective e.g. on preventing the pedestrian than cyclists accidents. In weighting, the effect estimate which indicated in percent changes was multiplied with the share (%) of relevant accidents. The calculations to obtain the changes in number of accidents were carried out by an Excel tool which was applied from the tool reported by Kulmala (2010) for structuring the accident data and effect estimates. The estimated non-usage of systems (e.g. due to annoyance) was taken into consideration in the calculations together with the penetration rate.

As the final result, the number of prevented road traffic fatalities and injuries per system in the EU-28 were calculated for 100% penetration rate (for relevant road users, vehicles and infrastructure). The effects were described as far as possible in numbers for the listed mobility aspects and comfort aspects. The calculated mobility effects of the systems were applied to calculate the change in total distance in trips, per year and transport mode based on the change in number of trips and the increase in trip length. As only scarce data on mobility and comfort are available, the results are presented based on assumptions of mobility and comfort, based on existing data. The

attempt was to make use of the best data available. The following countries are included in the mobility data: Belgium, Denmark, Finland, France, Germany, Great Britain, the Netherlands, Norway, Sweden and Switzerland, based on data from Post-harmonised travel data collected in the EU Cost Action TU0804 (Steenberghen, 2014). The effects on mobility were described as effects of the systems on change in total distance in trips, per year and transport mode.

The assessment of comfort was conducted on a 10-graded scale where the general comfort level, the starting point without the system is 5. The comfort level can vary from 0 (high discomfort) to 10 (very comfortable feeling). Values below 5 means reduced comfort and values above 5 means improved comfort with the system, compared to the situation without the system. The effects on comfort were described as effects of the systems based on the 10-graded scale, per year and road user per transport mode.

The results for 2020 and 2030 scenarios take into consideration the estimated penetration rates. The results presented in this paper consider only the effects of the systems on vulnerable road users.

### 3. Safety Assessment results

Fig. 1 shows the results of the safety impact assessment. Fig. 1a shows the overall impact (%) of systems on all road fatalities in the EU-28 at 100% penetration rate, with the low, medium and high effect ranges. The results in Fig. 1a show that Pedestrian and Cyclist Detection System + Emergency Braking (PCDS+EBR) and VRU Beacon system (VBS) are estimated to be the most effective systems in preventing fatalities and injuries in traffic when considering full penetration, while GWC, IVB and IPT have the smallest effects. These systems are also the most effective systems for pedestrians. For cyclists the most effective systems are PCDS+EBR and Bicycle-to-vehicle communication (B2V), while for moped riders and motorcyclists the most effective system is Powered Two Wheelers oncoming Vehicle information (PTW2V), followed by Cooperative Intersection safety (INS) and VBS. The estimates for PCDS+EBR show the maximum reduction of 7.5% on all road fatalities, which comes down to an estimate of over 2,100 fatalities saved per year when considering the 2012 accident data adjusted with the estimates accident trends. These effects are considerable and suggest that some of the selected systems will be able to make a significant contribution to a reduction in vulnerable road user fatalities and injuries.

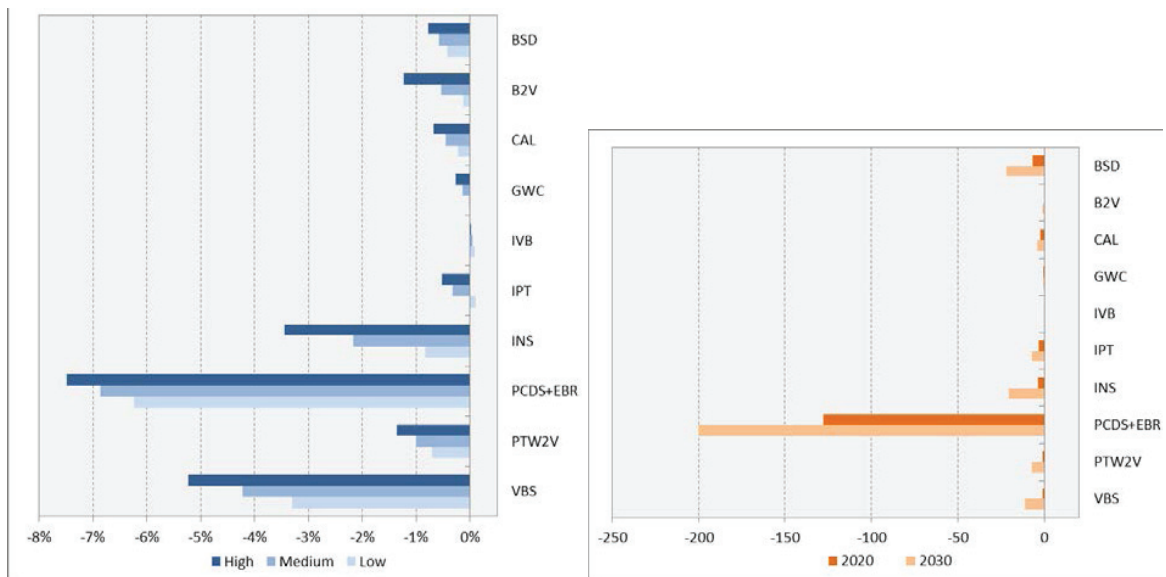


Fig. 1 (a) The overall impact (%) of systems on all road fatalities in the EU-28, 100% penetration rate. High/medium/low indicate the range of the estimate; (b) The overall medium impact of systems in number of fatalities in the EU-28 when considering the estimated accident trends and penetration rates.

The overall impacts of the ten ITS in the EU-28 for the future scenarios (2020 and 2030) in number of fatalities are presented in Fig. 1b. These numbers are calculated for the medium estimated effect and the medium estimated

penetration rate taking into consideration the, and estimated accident trends. Quite low penetration rates were assumed based on questionnaires assigned to authorities and manufacturers of ITS. The results showed the highest effects in number of fatalities per system in the EU-28 for PCDS+EBR (-200 fatalities), Blind Spot Detection (BSD) (-22 fatalities), INS (-20 fatalities) and VBS (-11 fatalities).

The results of safety impact assessment for 100% penetration rate indicate the full potential of the systems when all relevant road users, vehicles and infrastructure are equipped with the system. Furthermore, 100% usage and 100% reliability of the system is assumed where this can reasonably be expected. The results consider only the effects of the systems on vulnerable road users (i.e. accidents between vehicles and vulnerable road users). However, it is likely that some systems (such as INS and PCDS+EBR) will be made available as updates to systems that affect vehicle-vehicle collisions, but those effects are not considered in this assessment.

There are three main factors which explain how powerful systems are in contributing to traffic safety: 1) Targeted vulnerable road user groups: three of the systems target all vulnerable road users (BSD, INS and VBS) whereas three of the systems target only cyclists (BSV, GWC and IVB) and two systems only pedestrians (CAL and IPT), 2) Extent of the safety problem the systems targets: As mentioned earlier IVB is not expected to have any direct safety effects and it is rather expected to increase the mobility and comfort of the cyclists. Some of the systems (BSD, CAL, GWC and IPT) are targeting very specific situations and thus it is expected that their safety effects are more limited than the safety effects of systems targeting all accidents (or a large proportion) between cars/trucks/busses and relevant vulnerable road users (B2V, INS, PCDS+EBR, PTW2V and VBS), and 3) Degree of intervention: The Pedestrian detection and Emergency braking system (PCDS+EBR) is the only system which intervenes if the driver is not reacting to the warning and hence it was expected to have a relatively high impact on safety.

It must be noted that our safety impact assessment estimates the effect of future systems in future scenarios and there is uncertainty in the estimates for the numbers of avoided fatalities and injuries in the EU-28. In general, we can have uncertainty related to a) estimates of safety effects (they depend on the findings from literature and the knowledge of involved internal and external experts), b) accident data (for some systems we have better data for accident types the system aims to prevent than for some other ones), c) estimated accident trends, and d) estimated penetration rates. The uncertainty in the safety effects were addressed by providing low, average and high values for all the estimates related to each relevant safety mechanism. Uncertainties in accident data and accident forecasts were not addressed. During the assessment process it became clear that the yearly number of injuries reported to CARE database and to national databases does not correctly reflect the situation in reality. The underreporting of injuries is common and the extent of this problem varies among countries. For fatalities the data are of better quality but not perfect either. Therefore, the results in this paper concern only fatalities.

#### 4. Results mobility and comfort assessment

The aim of the mobility and comfort impact assessment was to determine the impact mechanisms through which the ITS services affect the mobility and comfort of vulnerable road users, describe the effects, and to provide quantitative estimates for the impacts of the selected ITS when they are fully deployed and within selected future scenarios (2020 and 2030). The impact assessment determined how the selected ITS affect the mobility and comfort experienced by vulnerable road users.

Fig. 2a shows the estimated medium impact on comfort for the 10 systems at 100% penetration rate. The system with the highest effect on comfort at 100% penetration is PTW2V, followed by B2V, which both have similar aims but are directed at different VRU groups. The reduced chances of accidents will improve subjective safety and reduce stress during travelling, especially in complex situations (e.g. signalised intersections with many traffic streams), but too many warnings can reduce the comfort in a busy environment.

The assessed comfort effects resulted in comfort values. These values were then applied with general improvement in comfort due to improved safety in general for the years 2020 and 2030, and with the penetration rates including non-usage. The comfort gains are reduced accordingly. The values are presented in Fig. 2b. When taking the estimated penetration rates into account, the system resulting in the highest increase in comfort for pedestrians is IPT, for cyclists PCDS+EBR, and for PTW riders PTW2V.

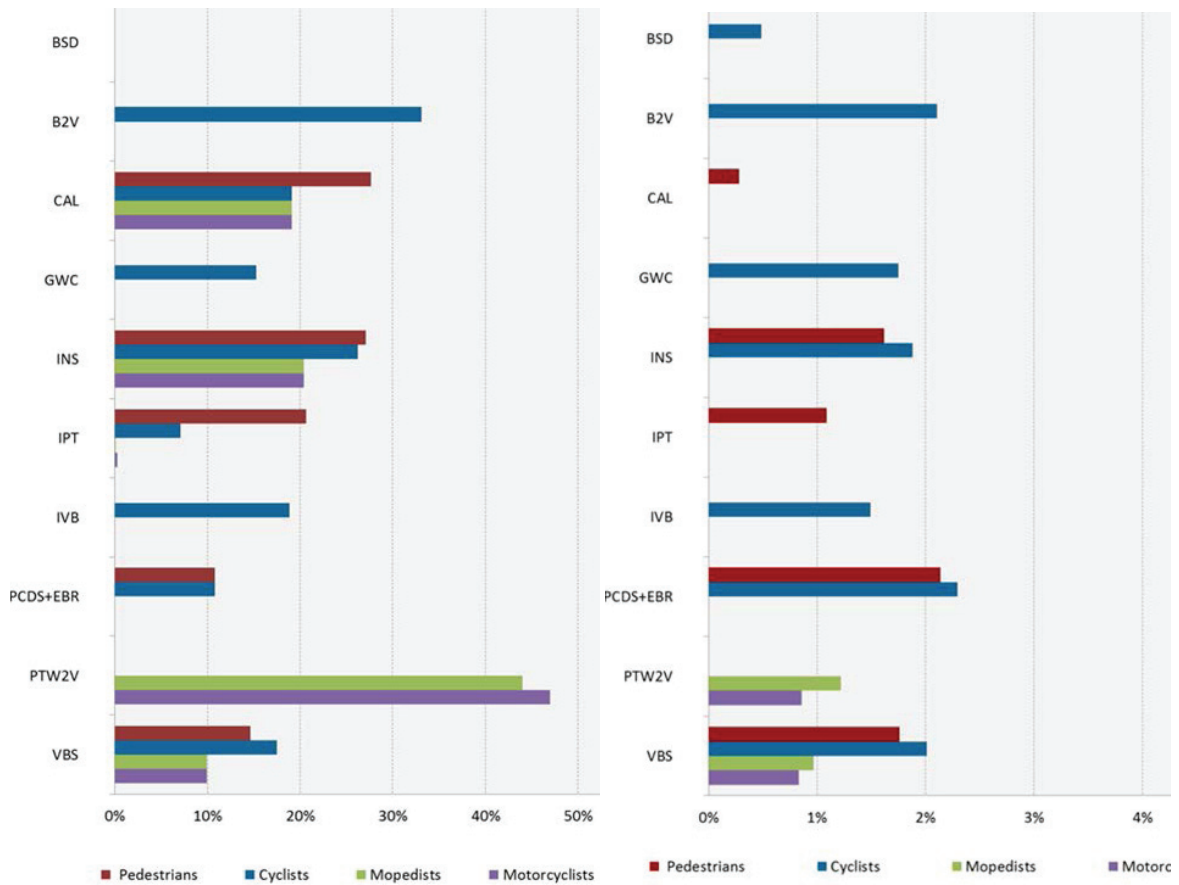


Fig. 2. The average overall impact (%) of systems on (a) comfort and (b) mobility by VRU type, 100% penetration rate.

The overall effects on mobility for each road user group are presented in Fig. 3a below for the ten systems. The figure shows the medium estimate of the effect for 100% penetration rate. The system with the highest effect on mobility is PCDS+EBR, followed by B2V. The mobility assessments were then applied with general increase in mobility; the general mobility trends as described by Chatterjee, and Gordon (2006), and with the penetration rates including non-usage. The system with the highest mobility change for 2030 including reduced penetration rates including non-usage is PCDS+EBR, both for cyclists and for pedestrians. The mobility changes for PTW riders were very small.

### 5. Environmental assessment

Although, environmental benefits are not the prime aim of the adoption of these systems and even as environmental benefits are not expected to be substantial for the majority of systems, it is important to understand the extend of the impacts the selected ITS systems might have on the environment.

The assessment of the environmental benefits from the use of the ITS focuses on the modification of the transport demand. Therefore, the environmental benefits in this impact assessment approach are linked to the mobility impact of the ITS through impacts on: trip destination (e.g. longer existing trips); route choice (e.g. choice of shorter alternative routes); generation of new trips and modal shift. Within the category of environmental impacts, the major external impact categories of mobility have been considered, namely the contribution to air pollution, climate change (including up- and down-stream impacts of fuel consumption) and noise levels. The environmental impacts

of the systems are calculated by multiplying the mobility changes of PTW's and cars with the emission factors per km of PTW's and cars respectively and the cost unit values for these impact units.

## 6. Cost-Benefit Analysis results

The Cost Benefit Analysis aims to aggregate and compare in monetary terms the different impact elements that are produced from the implementation of the 10 ITS. The CBA methodology developed to assess the impacts of ITS as estimated in the VRUITS project, has been described by Mans et al. (2014). The Guide to Cost-Benefit Analysis of investment projects of the European Commission (2008) provides the framework for the CBA. The CBA is carried out from an EU-27 perspective, and is based on the comparison of the situation where the examined ITS service is deployed, to the business-as-usual case where no such service would be available. The costs and benefits of the systems are calculated on an EU level and no specifications are given on a country or city level. After defining the costs involved for the installation and operation of the different versions of the examined ITS, this CBA method considers the impacts these ITS would have in the fields of safety, mobility (travel time and travel costs), comfort and environment. The monetisation of the safety impact follows the guidelines for definition of the costs of accidents as developed by Bieckel et al. (2006). The monetisation of the direct mobility impacts takes into consideration the value of the change in the number, duration, mode and length of trips conducted by different road user groups as a consequence of the introduction of the examined ITS. The monetisation of comfort is based on the existing practice in the field of public transport where the Value of Time is connected to the comfort level of passengers. A simplified estimation of the potential environmental benefits of ITS is made, focusing on the impacts on emissions due to a change in the overall modal shift and passenger-km carried out per mode.

The overall performance of these systems has been assessed based on the Net Present Value (NPV) and the benefit/cost ratio indicators in order to compare how beneficial they are to society. The NPV estimates the level of benefits and costs that are generated by system implementation accounting for a discounting factor for costs and benefits generated in the future, indicating the impact of implementing each system on society. The benefit/cost ratio produces an estimation of the level of benefits generated by each unit of costs caused by implementing each system. This assessment of the performance, calculated for the medium effect and penetration rate, of the systems on these indicators is presented in Table 2.

Table 2. CBA indicators for the 10 ITS.

	INS	PTW2V	VBS	CAL	B2V	GWC	IVB	IPT	BSD	PCDS+EBR
NPV (in M€)	2,155	1,061	677	169	114	6	-368	-553	-12,948	-36,529
Benefit/Cost ratio	7.9	20	2.6	1.8	4.8	1.5	-0.1	0.5	0.2	0.3

Out of the 10 systems assessed, 6 seem to have positive results considering their Net Present Value of costs and benefits. The best performing system in that aspect is INS (2.2 billion €). This system also delivers a very high level of benefits compared to the costs of implementing it.

Also the PTW2V and VBS systems yield a very high level of benefits according to their NPV values of (€1.1 bn and €677 m). Also interesting systems, in matters of NPV, are the CAL, B2V and the GWC which each yield a positive result. The rest of the systems (IVB, IPT, BSD and PCDS+EBR) have negative NPVs in the medium penetration rate scenario, which means that for these systems the benefits do not outweigh the costs. Especially for BSD and PCDS + EBR the costs are very high. These systems can only be made beneficial if the implementation costs were to be transferred partially to existing systems. The benefit/cost ratio allows for the estimation of the balance of costs and benefits of a system. It literally indicates how many monetary units of benefits in net present value are produced in return for every monetary unit of cost invested in a project in net present value. Here the order of the system performance is slightly different. The best performer on this indicator is PTW2V, followed by INS and B2V, showing an extremely positive return on the costs with values of 20, 7.9 and 4.8 respectively. Additionally, the VBS and the CAL systems have a positive performance regarding this indicator returning 2.6 and 1.8 Euros in benefits for every Euro invested in system costs. The benefit/cost ratio is under 1 for the IVB, IPT, BSD and PCDS+EBR system meaning that these systems produce more costs than benefits in the medium scenario.



Table 3 shows the safety, mobility and comfort benefits and the costs per system. The safety benefits seem to play a dominant role in most of the ITS.

Table 3. ITS impact costs of implementation and safety benefits for the different vulnerable road user groups (in M€).

System	Costs	Safety benefits	Mobility benefits	Comfort benefits
INS	312	2,024	99	333
PTW2V	56	577	28	516
VBS	428	1,014	50	44
CAL	213	331	14	37
B2V	30	96	5	44
GWC	11	14	1	3
IVB	340	-48	-2	14
IPT	1,039	351	15	107
BSD	16,034	2,769	133	165
PCDS+EBR	53,389	14,000	557	2,190

Fig. 3 presents the impacts of the systems on the road user groups. The distribution of system benefits differs largely for the 10 systems assessed. While the B2V, GWC and IVB target nearly exclusively bicycle users, the CAL and PCDS+EBR distribute their benefits between cyclists and pedestrians. PTW are the main VRU group that benefit from the VBS and PTW2V systems while the BSD system produces considerable benefits for both PTWs and cyclists. Finally, INS is a system producing well distributed benefits over all VRU groups opposed to IPT, a system producing benefits exclusively for pedestrians

### 7. Conclusions

The impact assessments and CBA results allow us to compare the selected 10 systems with each other. In the 2020/2030 projections, PCDS+EBR generates high impacts on safety, mobility and comfort. However, this is coming at high cost, as demonstrated by the negative NPV for safety benefits and the low benefit-cost ratio as far as VRU safety is concerned. Regarding the deployment path, on the one hand, the system is technically complex and hence deployment may run into some challenges. On the other hand, the system is scheduled for inclusion in the Euro NCAP tests in the near future.

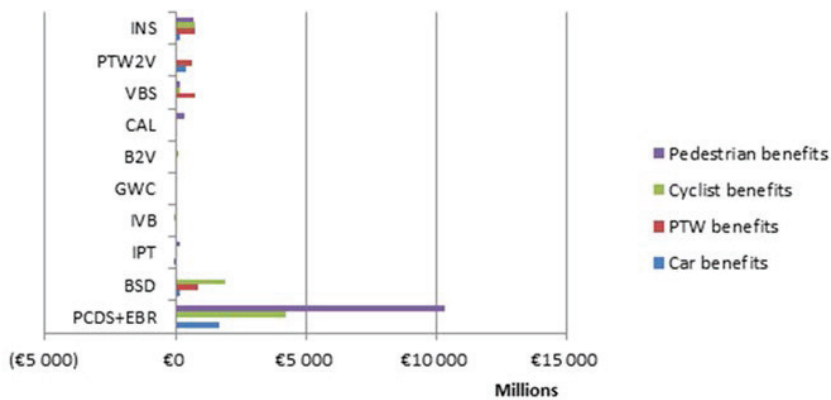


Fig. 3. ITS impact costs of implementation and safety benefits for the different road user groups (in M€).

The highest benefit-cost ratios for the safety benefits only are achieved by PTW2V, INS, B2V and VBS. All except B2V have a considerable NPV for costs and safety benefits for VRU's. This means that the socioeconomic figures of these systems are robust. This has indeed been shown in a sensitivity analysis; see Bax et al (2015). Of these 4 systems, INS and VBS have a good all-round safety impact for most VRU types; while the other two focus on specific VRU groups: PTW2V on PTWs, and B2V on cyclists. The systems IVB, BSD, IPT and PCDS + EBR have a benefit cost ratio lower than 1, which means that the benefits of these systems do not outweigh the costs.

It should be noted that the assessments include a lot of uncertainties. The estimates were based on available literature, and on expert judgement, when no data was available. In order to improve the accuracy of the estimates, better data is needed, such as data on accidents for the safety assessment, like number and details of the accidents; including hospital records, and trials to test the functioning of the systems and their effect on road user behaviour.

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